Hot dust around Sun-like stars: Confirmation of Candidates and Evidence for Transience

Rachel Smith, Institute for Astronomy, Edinburgh, rs@roe.ac.uk : Mark Wyatt, Institute of Astronomy, Cambridge

Abstract

Studies of the debris disk phenomenon have shown that most systems are analogous to the Edgeworth-Kuiper Belt (EKB). Recent observational studies have revealed a rare subset of sun-like stars that possess dust which lies, in contrast, in the terrestrial planet region. We carried out an observational programme to investigate the occurrence of this warm dust around Sun -like stars and compared the results to a simple analytical model. Several of the candidates prove to be bogus disks. We find that for most of the confirmed sources in the sample, an asteroid belt-like region in collisional equilibrium is unlikely to be the source of the emission, and an alternative explanation must be sought.

Introduction

Current theories of planet formation suggest that gas giant planets are likely to form in the regions from a few to a few tens of AU from the central star. The processes involved in their formation and subsequent gravitational effects of these planets should keep these regions relatively dust free. It was something of a surprise therefore, when some 25% of IRAS identified excess sources were shown to demonstrate excess in the mid-infrared only, and not the cooler excesses typically associated with Edgeworth-Kuiper belt like regions (Zuckerman 2001). When we consider Sun-like stars however, the situation is a little different, with hot excess emission found around some 2% of stars (see e.g. Bryden et al 2006). We used analysis of the IRAS database together with a literature search to compile a list of likely warm dust hosts of F, G and K spectral types. Stars were observed using multi-wavelength photometry. These observations were used to confirm the purported excesses, to constrain SED fits and to place limits on the possible extension of the disks. In parallel to the observations, a simple analytical model, similar to that of Dominik and Decin (2003), has been developed to describe the evolution of a planetesimal belt in collisional equilibrium. This model is compared to the observational results to determine the nature of the excess emission: an asteroid belt-like region in collisional cascade, or is the dust emission transient in nature?

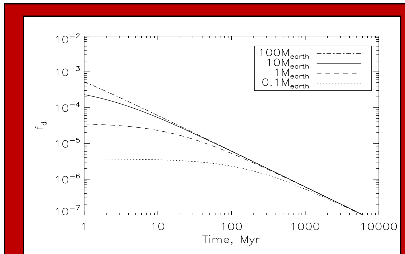

Figure 1: A plot of the fractional excess vs. time for disks of varying initial mass. Note that at late times fractional excess is not dependent on initial disk mass.

Observations

The observational programme for our sample was split into two stages:

• Firstly, the TIMMI2 instrument on the 3.6m telescope at La Silla was used to confirm the excess was both real and centred on the star.

• The second stage of observations was follow-up of confirmed sources on 8m class instruments. The bulk of these observations were completed with the VISIR instrument on the VLT, with further observations on the MICHELLE Gemini instrument. Photometry was performed at 10 and 18 μm. Imaging allowed a search for extension around these objects. The lack of any such detection for our objects allows us to place upper limits on the maximum disk radius (see fig. 3).

• **RESULTS :** The following stars are confirmed as possessing hot excess emission centred on the star ; η corvi (see fig. 2 for SED), HD12039, HD69830, HD128400, HD191089.
For stars HD53246, HD65277, HD79873 and HD123356 the excesses were found to be from background objects. HD10800 no longer displays any excess (also confirmed by Bryden et al. 2006), and may be a statistical anomaly, or perhaps this system has evolved since the epoch of the IRAS observations.

Star HD	Spectral type	Age Myr	Radius AU	$F_{obs}=L_{IR}/L_*$ $\times 10^{-3}$	F_{max} $\times 10^{-3}$	Transient	Reference
12039	G3/5V	30	4-6	0.1	0.2	Not Required	Hines et al. (2006)
69830	K0V	2000	0.3	0.2	0.00013	Yes	Beichman et al. (2005)
109085 (η corvi)	F2V	1000	1-2	0.5	0.00015	Yes	Wyatt et al. (2005)
128400	G5V	300	0.3	0.9	0.000014	Yes	Gaidos (1999)

Table 1: The objects with excess emission confirmed in this project. Transience is confirmed for objects in which f_{max} as determined by the model is 100x less than the observed infrared fractional excess.

Model comparison

The model describes the evolution of a planetesimal belt under a collisional cascade in equilibrium. A key prediction of the model is that there is a maximum possible luminosity that a disk of given radius and age can have. The reason is that increasing the initial disk mass does not increase the mass at late times (see fig. 1), as more massive disks process their material at a higher rate.

$$F_{max}=L_{IR}/L_* = 0.16 \times 10^{-3}\, r^{7/3}\, t^{-1}$$

The predicted maximum fluxes for each system is strongly dependent on disk radius, and so information about the dust location is crucial to our predictions.

A comparison of our results with the predictions of the analytical model is given in Table 1. For all but one of our confirmed hot dust-hosting F,G and K type stars, whose ages range from 0.03-2 Gyr, the high levels of excess emission can not explained by a steady-state collisional cascade. Further investigation of the possibility of a single massive collision producing an unusual amount of dust in an otherwise quiescent disc suggests that this is also an unlikely source of the emission. The hot dust in these objects must be transient.

Case of η corvi

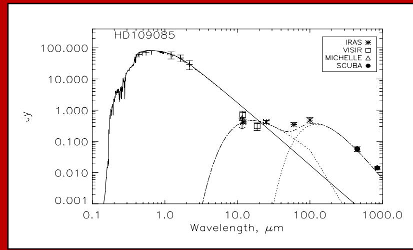

Figure 2: The SED of η corvi. An alternative three temperature fit is also possible (Chen et al. 2006).

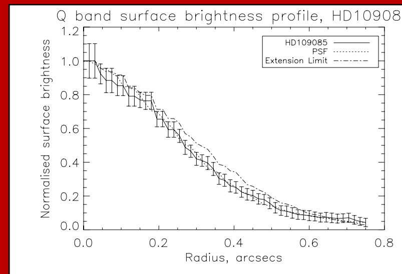

Figure 3: The Q band surface brightness profile of η corvi, with that of a standard for comparison. No extension was detected. A series of models convolved with the measured PSF were tested to determine extension limits. Here a disk at 0.2" (3.8AU) radius would just have been detected.

Implications and Conclusions

• Even allowing for the uncertainties in our modelling assumptions, several of our objects have excess emission way above that which could be expected from a coincident collisionally evolving belt. Thus we must conclude that the source of this emission is transient in nature.

• Further modelling has shown that one possibility often suggested as a source for this emission - a recent massive collision in an otherwise steady state belt - is highly unlikely to account for most of the hot dust sources.

• Additional possibilities for the unusually high emission of these older sources are a showering of comets or the sublimation of a massive super-comet caused by the recent stirring of the outer planetesimal belt, due to planet migration, resonance crossing or recent stellar fly-by. A full investigation of these possibilities is being carried out.

References

- Beichman C.A., et al., 2005, ApJ, 626, 1061
- Bryden G., et al., 2006, ApJ, 636, 1098
- Chen C.H., et al., 2006, astro-ph/0605277
- Dominik C. & Decin G., 2003, ApJ, 598, 626
- Gaidos E.J., 1999, ApJ, 510, L131
- Hines D.C., et al., 2006, ApJ, 638, 1070
- Künzli M. & North P., 1998, A&A, 330, 651
- Rieke G., et al., 2005, ApJ, 620, 1010
- Wyatt M.C., et al., 2005, ApJ, 620, 492
- Zuckerman B., 2001, ARA&A, 39, 549

The Institute for Astronomy on the site of the Royal Observatory Edinburgh